AES - Advanced Electric Systems & Aerodynamics for Efficiency Improvements in Heavy Duty Trucks NT 42189

Heavy Vehicle Systems Optimization

April 20, 2006

U.S. Department of Energy
Energy Efficiency and Renewable Energy

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AES Project Objectives

The goal of this project is to improve the fuel efficiency of heavy-duty trucks through improvements in cooling system performance, air system management, and advanced power management.

- Analyze, design, build, and test a cooling system that provides a minimum of 10% greater heat rejection in the same frontal area, with no increase in parasitic fan load.

- Quantify the effect of aerodynamic drag due to the frontal shape mandated by the area required for the cooling system.

- Realize fuel savings with advanced power management and acceleration assist, utilizing the integrated starter generator and energy storage devices.

- Develop an intelligent vehicle air management system, whereby the vehicle air system compressor is decoupled from the engine and is incorporated into an air system supply module.

Project Benefit Opportunities

Heavy-Duty on-road:1% Fuel Economy Improvement = $2,350 PV

- to end customer at $2.70/gallon, 125,000mi/yr, 5 year, 6.0 mpg baseline

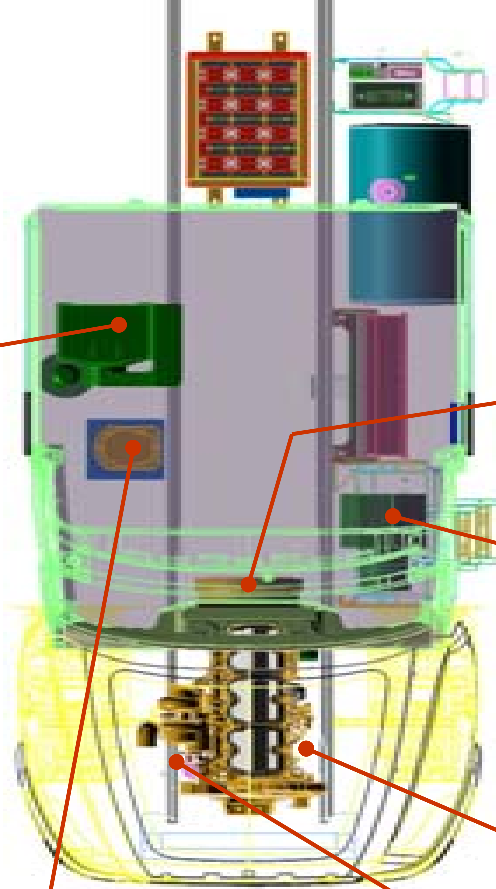
	Fuel Consumption Imrovement		Heat Rejection Improvement	
	Range %		Range %	
Advanced Electric Systems	Low	High	Low	High
Aerodynamic Drag	0.0	3.0		
Electric Air Compressor	0.3	0.5	0.5	1
Advanced Power Management	1.0	4.0		
Elevated Coolant Temperature	1.0	3.0	2	4
Hi Efficiency Aftercooler	0.2	0.5		
Auxiliary Oil Cooler	0.2	0.5	2	4
Electric Cooling Fan	0.0	1.0	5	7
Total AES	**2.7**	**12.5**	**9.5**	**16**
More Electric Truck				
MEI Components	1	2		
Idle Reduction	5	7		
Total MET	6	9		
Total MET and AES	**8.7**	**21.5**	**9.5**	**16.0**

10% On-road fuel economy improvement = 2000 gal / yr savings

Combine with 1800 gal / yr idle reduction = 3800 gal / yr

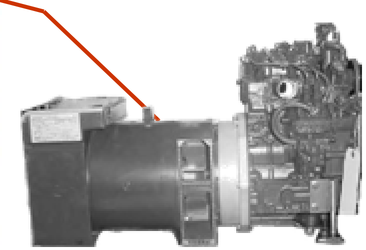
Spread over 500,000 Class 8 Trucks = 1.9 Billion Gallons / yr ➔$5.2 Billion @ $2.75/gal

Builds Off "More Electric Truck" Existing Architecture

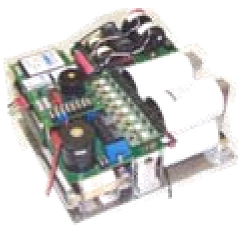


Modular HVAC
Variable speed compressor more efficient and serviceable
3X more reliable compressor no belts, no valves, no hoses leak-proof refrigerant lines instant electric heat

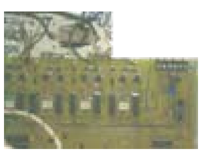
Integrated Starter Generator
Beltless engine product differentiation
improve systems design flexibility
more efficient & reliable accessories



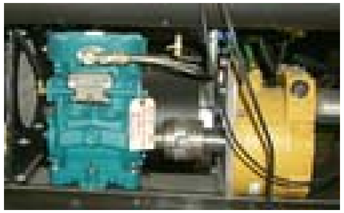
Auxiliary Power Unit
Supplies DC Bus Voltage when engine is not running - fulfills hotel loads without idling main engine overnight



Shore Power Converter
Supplies DC Bus Voltage from 120/240 Vac 50/60 Hz Input



Down Converter
Supplies
12 V Battery from DC Bus

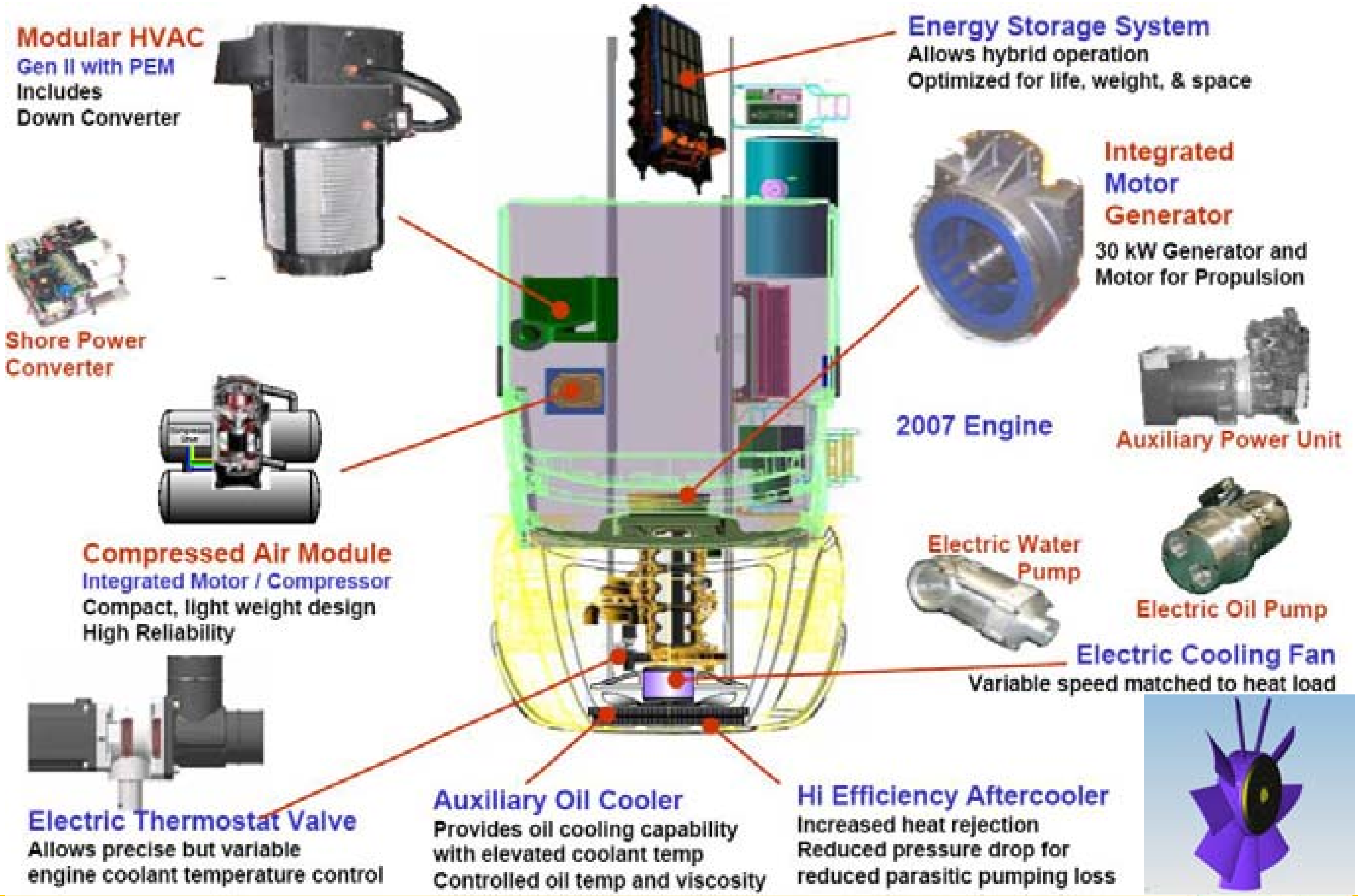


Compressed Air Module
Supplies compressed air for brakes and ride control

Electric Water Pump
Higher reliability variable speed faster warm-up less white smoke lower cold weather emissions

Electric Oil Pump
Variable speed
Higher efficiency

Caterpillar C-15 with ISG


Modular HVAC
Gen II with PEM
Includes
Down Converter
Energy Storage System
Allows hybrid operation
Optimized for life, weight, & space
Integrated
Motor
Generator
30 kW Generator and
Motor for Propulsion
Shore Power
Converter
2007 Engine
Auxiliary Power Unit
Compressed Air Module
Integrated Motor / Compressor
Compact, light weight design
High Reliability
Electric Water
Pump
Electric Oil Pump
Electric Cooling Fan
Variable speed matched to heat load
Electric Thermostat Valve
Allows precise but variable
engine coolant temperature control
Auxiliary Oil Cooler
Provides oil cooling capability
with elevated coolant temp
Controlled oil temp and viscosity
Hi Efficiency Aftercooler
Increased heat rejection
Reduced pressure drop for
reduced parasitic pumping loss

Motor Cooling Fan Motor – 20 kW @ 2000 rpm

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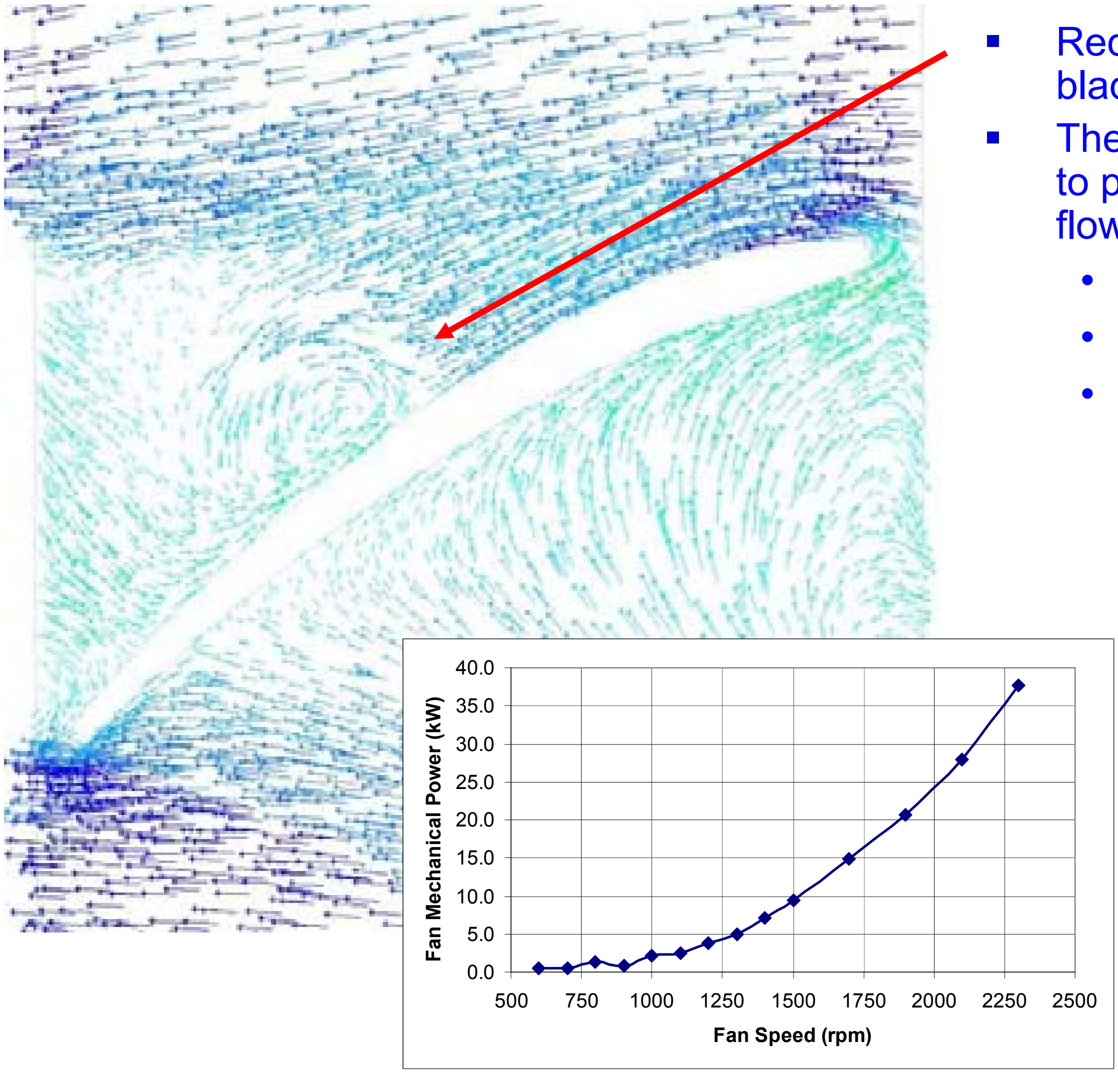
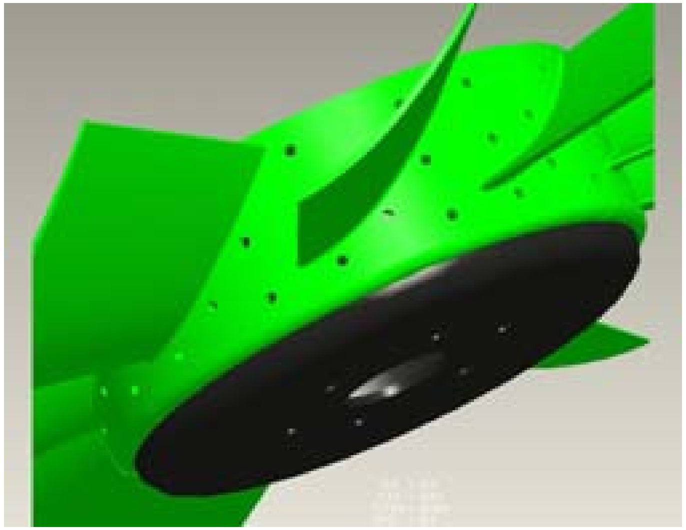
Blade Design



- Reduce separation and turbulence at blade root.
- The objective of the new fan design is to provide 10% increase in the air flow with the same input power.
  - Inner diameter – 15 inches
  - Outer diameter – 34 inches
  - Blades – 9



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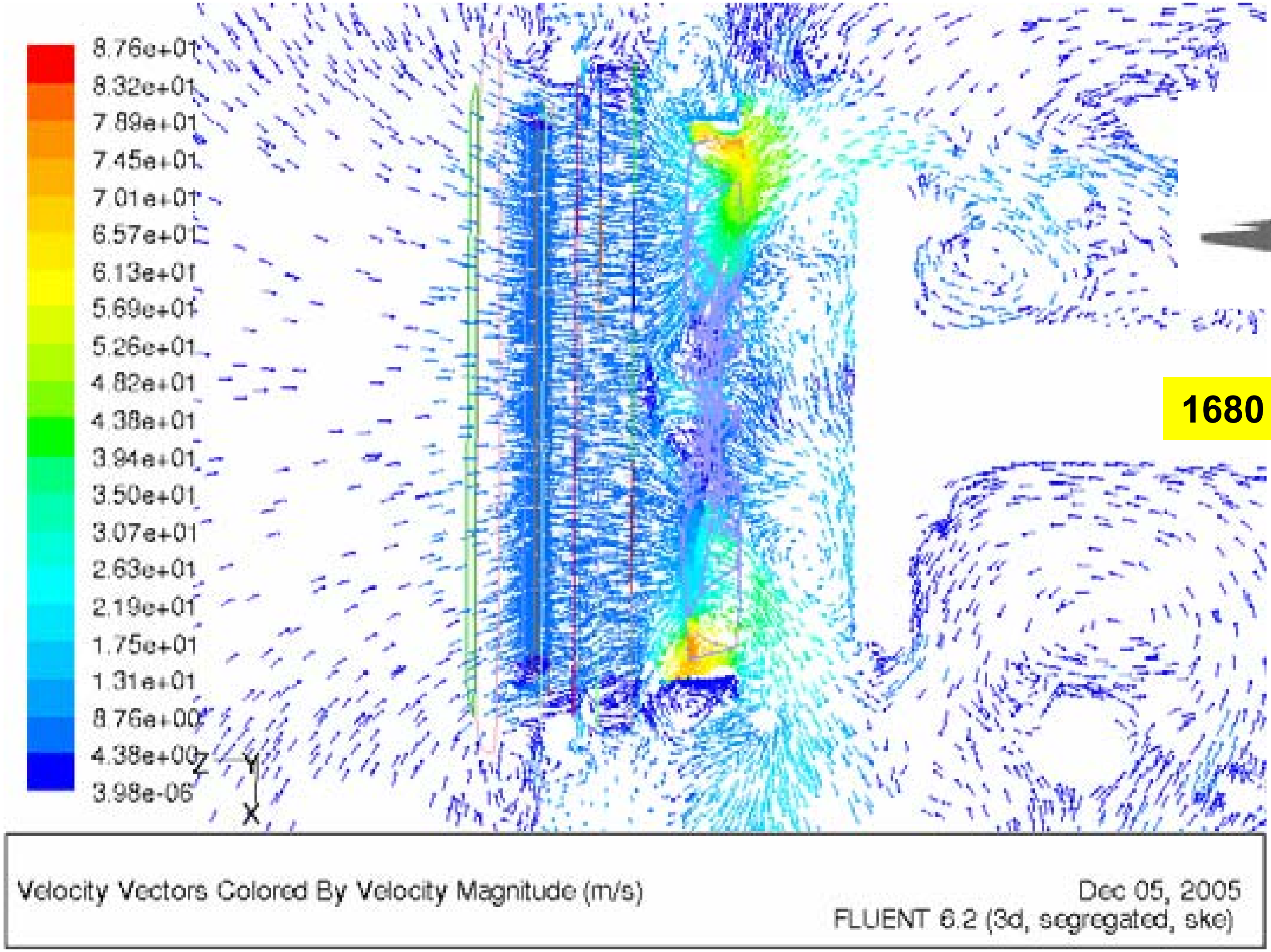
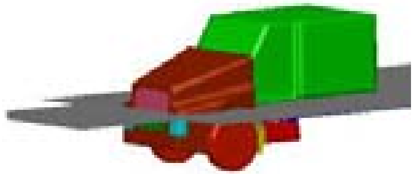
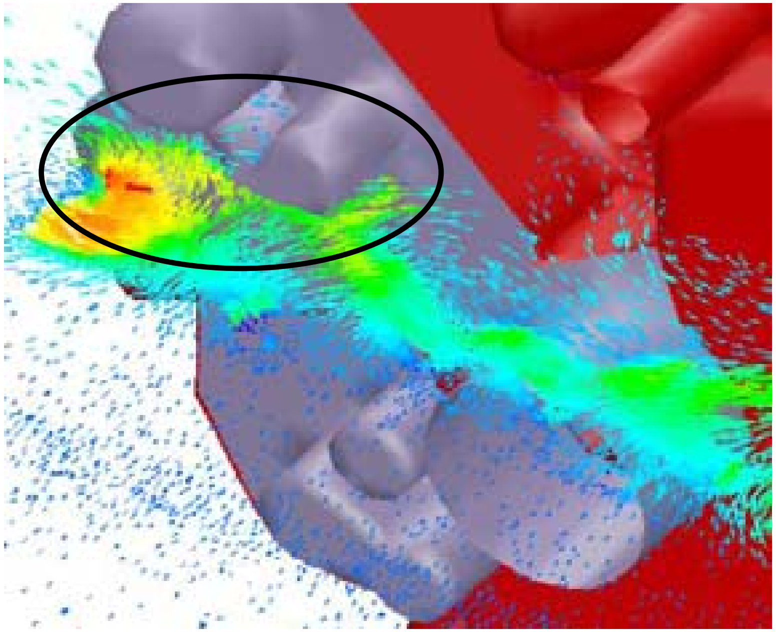
T2000 Underhood CFD Analysis
Cooling Design Center and Champaign Simulation Center

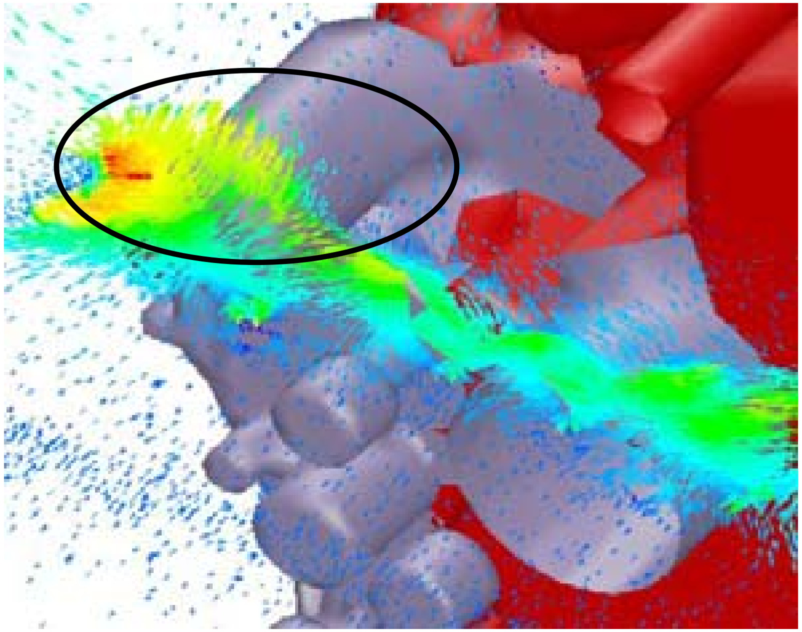




1680 rpm, 0 ram air

Front End Accessories Drive



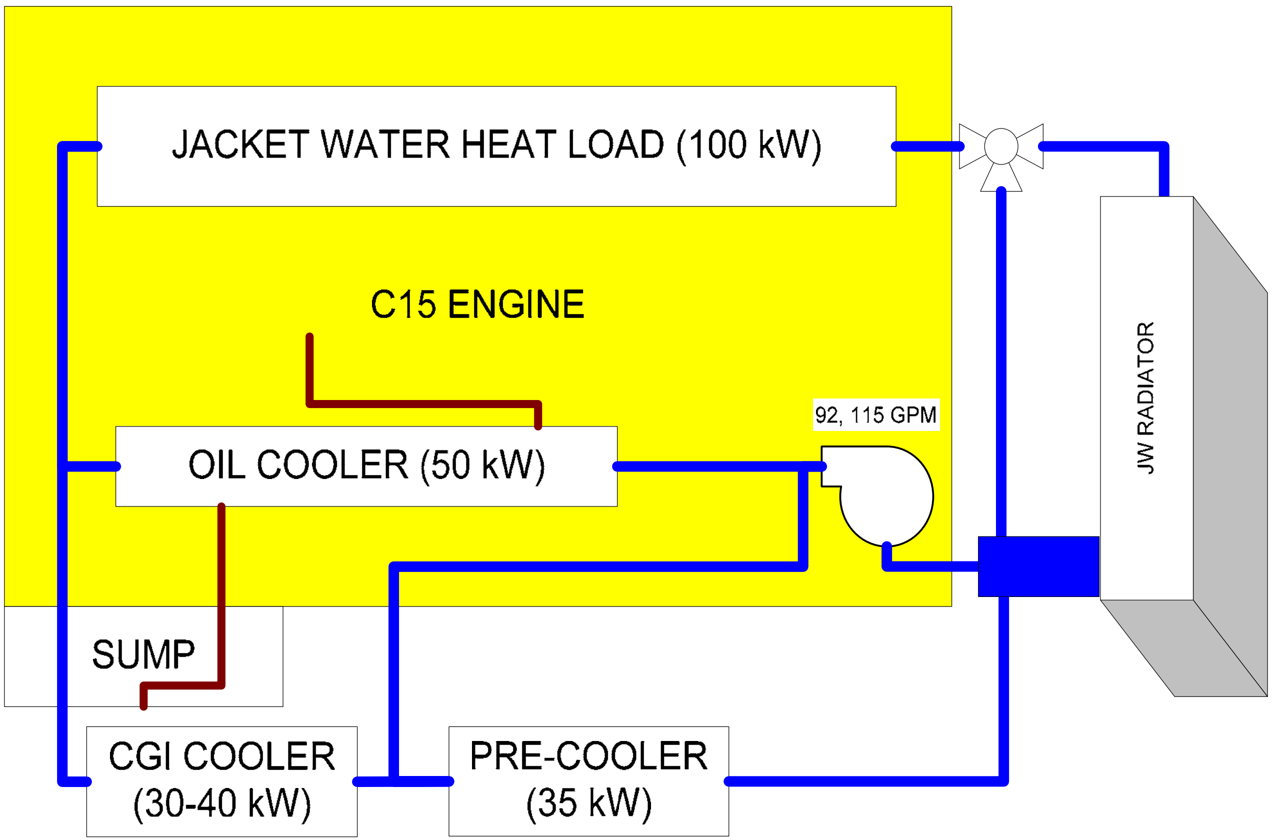


Old FEAD (baseline) **New FEAD**

Previous Underhood CFD Study

- **Small** change in FEAD frontal area shows significant improvement in airflow – **6%**
- Accessories in close proximity to cooling fan (<12 inches) have very large effect on airflow
- **MEI reduction in engine frontal area (beltless engine) has potential for much larger airflow improvement**

Cooling System Schematic



Electric Valve

- Maintain constant coolant temperature
- Elevate top tank temperature
- Reduce 20 kW cooling fan usage
- Reduce water pump speed and power

Elevated Coolant Temp

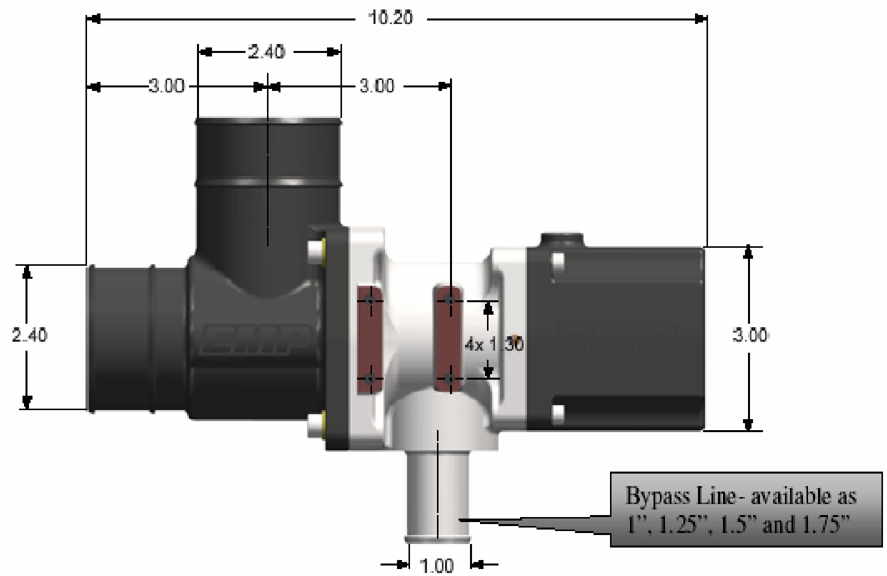
- Improve fuel economy by increasing engine efficiency
- Potential for increased heat rejection

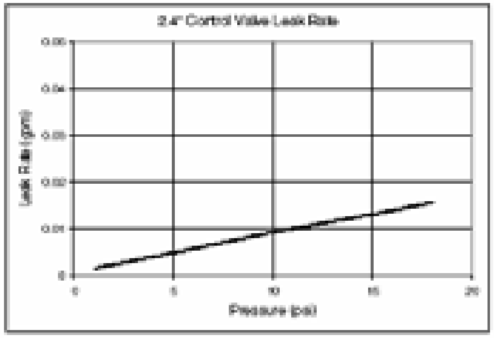
Electric Thermostat Valve

ENGINEERED MACHINED PRODUCTS INC

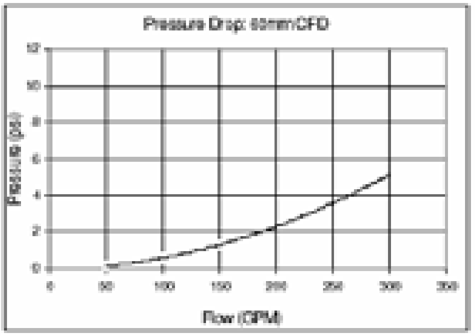
POWERING THE FUTURE

2.4" Control Valve Summary – Production 2005





- ✓ Can seal up to 25 psi at 12V, up to 25 psi at 24V
- ✓ Can divert all flow to radiator in 16 seconds
- ✓ Accurate temperature control, ± 3° C



- ✓ **Valve Materials** – Industry wide accepted materials for under hood applications
- ✓ **Flow Diverter** – Amodel AS6115. High temperature, water resistant nylon
- ✓ **Piston Housing and Motor Cover** – Amodel AS1933 High temperature, high strength water resistant nylon

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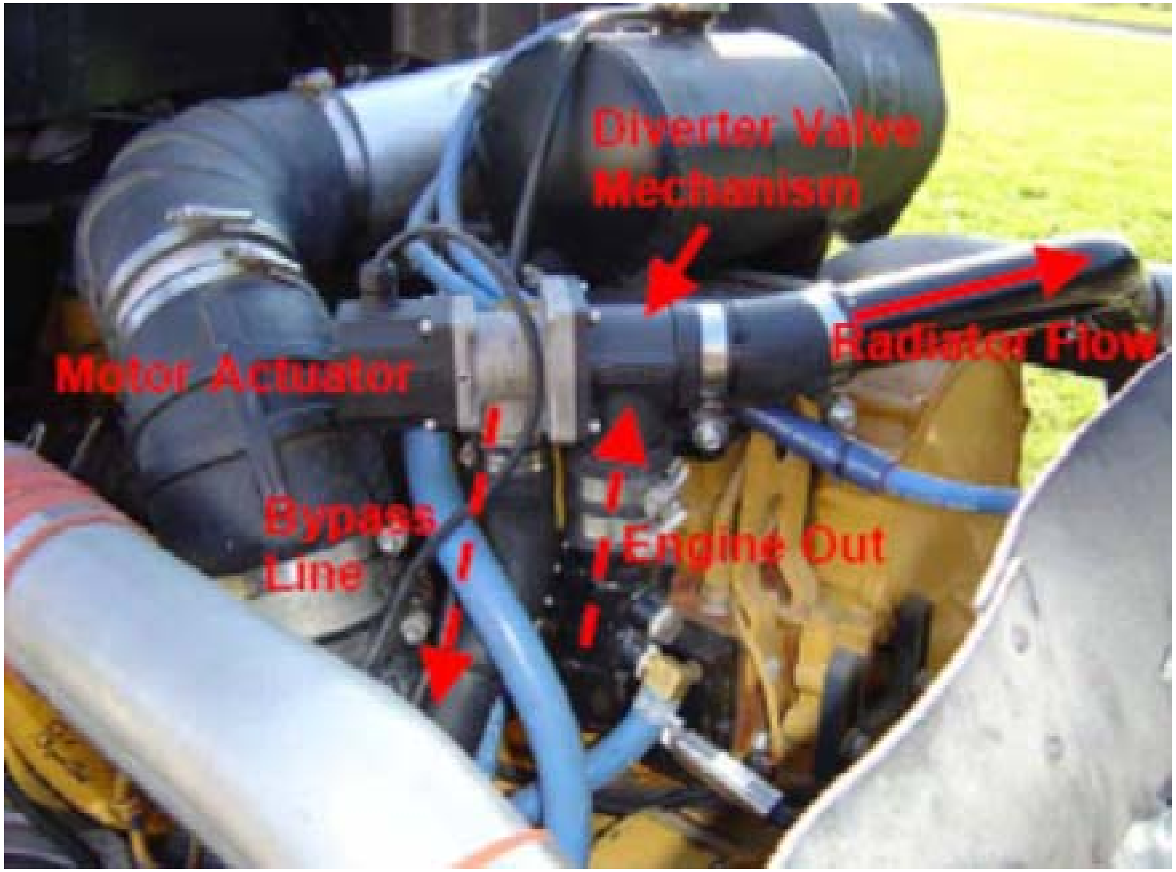
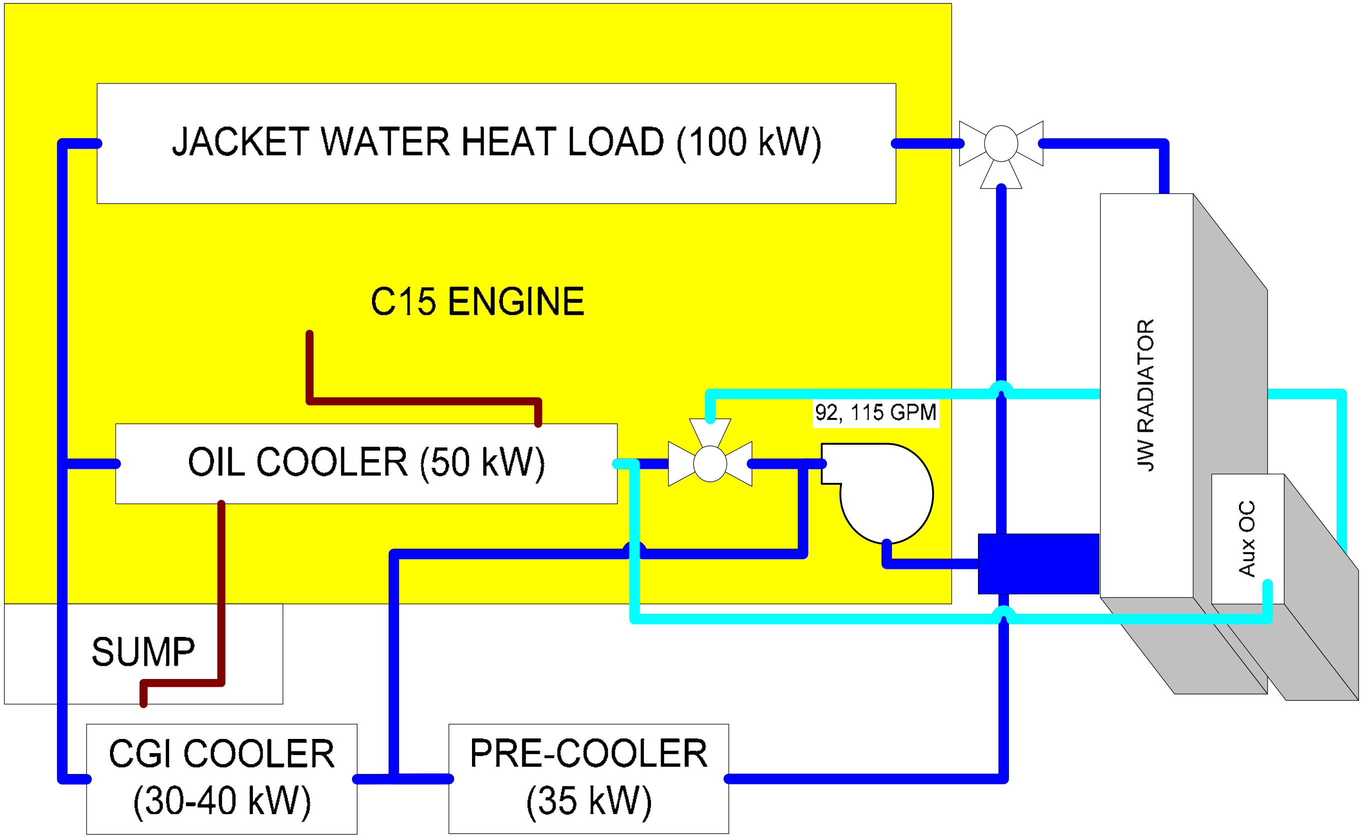
Valve Installed in MET



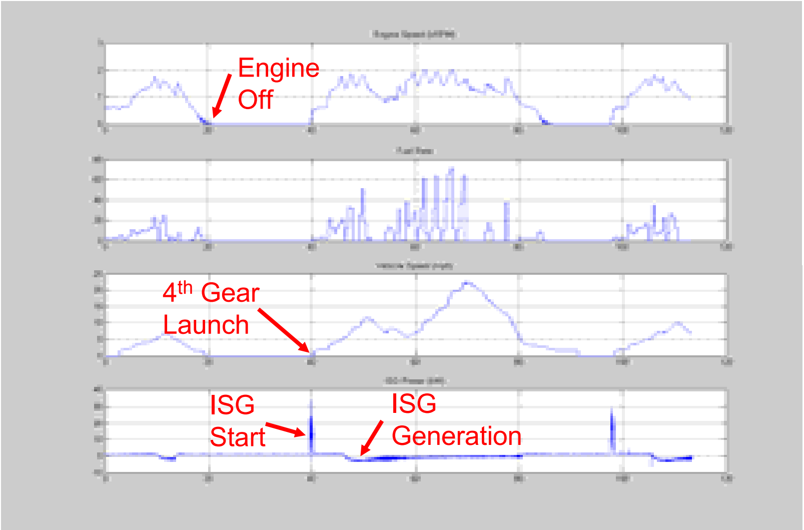
Oil Cooling



Objectives

- Reduce engine oil temperature to a safe operating temperature, in the presence of higher coolant temperatures.
- Minimize space claimed by oil cooling system components.
- Optimize oil temperature to reduce engine friction reducing heat rejection further.

Advanced Power Management



- Opportunity exists to absorb braking energy during tight cruise control conditions in uneven terrain, distribute power to accessories, or store.
- Want to maximize value of existing ISG and power distribution system.
- Use acceleration assist in urban drive cycles; cruise assist on hilly roads.
- Simulation shows 1 to 4% fuel consumption decrease, dependent on terrain.
- Explore energy storage technologies – seek to minimize cost, volume, and weight.

Energy Storage

Objectives

- Maintain 300V bus for electric components.
- Provide power to Integrated Starter Generator (ISG) for engine assist up to 60 mph
- Provide more energy per volume for the limited space available.
- Provide more battery pack life for energy cycling requirements.

Requirements

- Provide 35 kW for 100 seconds:
  - 30 kW for the integrated starter generator (ISG) at full power in engine assist mode
  - Assumed 5 kW miscellaneous load (electric components)
  - 1.0 kWh of energy in a typical cycle
  - Acceleration time from 0-60 mph: 100 sec
- 30 kW needed in cold conditions (-18°C)
- Min and max voltage: 250V to 360V

Results

- Provide 4 years of life
  - Assumed 300 days/yr.
  - 500 mi./day
  - 15 accel-decel cycles/500mi.
  - 50 hill cycles/500 mi.
  - 15 city driving cycles/day
  - 80 cycles/day
  - 96,000 cycles/life

- Based on our requirements and our battery and ultra-cap data, we can find an approximate weight, size, and cost for each technology.
- For our application, NiMH has the lowest cost, weighs the least, and is the smallest size.
- The only downfall of NiMH is its poor performance at low temperatures.

2007 MY Integration

2000 C15 500 HP Heat Loads from Data
ATAAC (77 kW)

JACKET WATER HEAT LOAD (81 kW)
CAC PRE-COOLER (0 kW)
OIL COOLER (50 kW)
CGI COOLER (0 kW)
JW Total (131 kW)

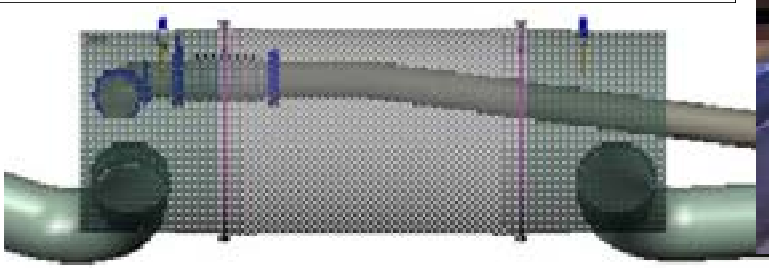
Cooling System Total (208 kW)

Increased need for heat rejection is motivation for More Electric Cooling

2007 C15 550 HP Heat Loads from Data
ATAAC (110 kW)

JACKET WATER HEAT LOAD (100 kW)
CAC PRE-COOLER (34 kW)
OIL COOLER (50 kW)
CGI COOLER (40 kW)
JW Total (224 kW)

Cooling System Total (334 kW)



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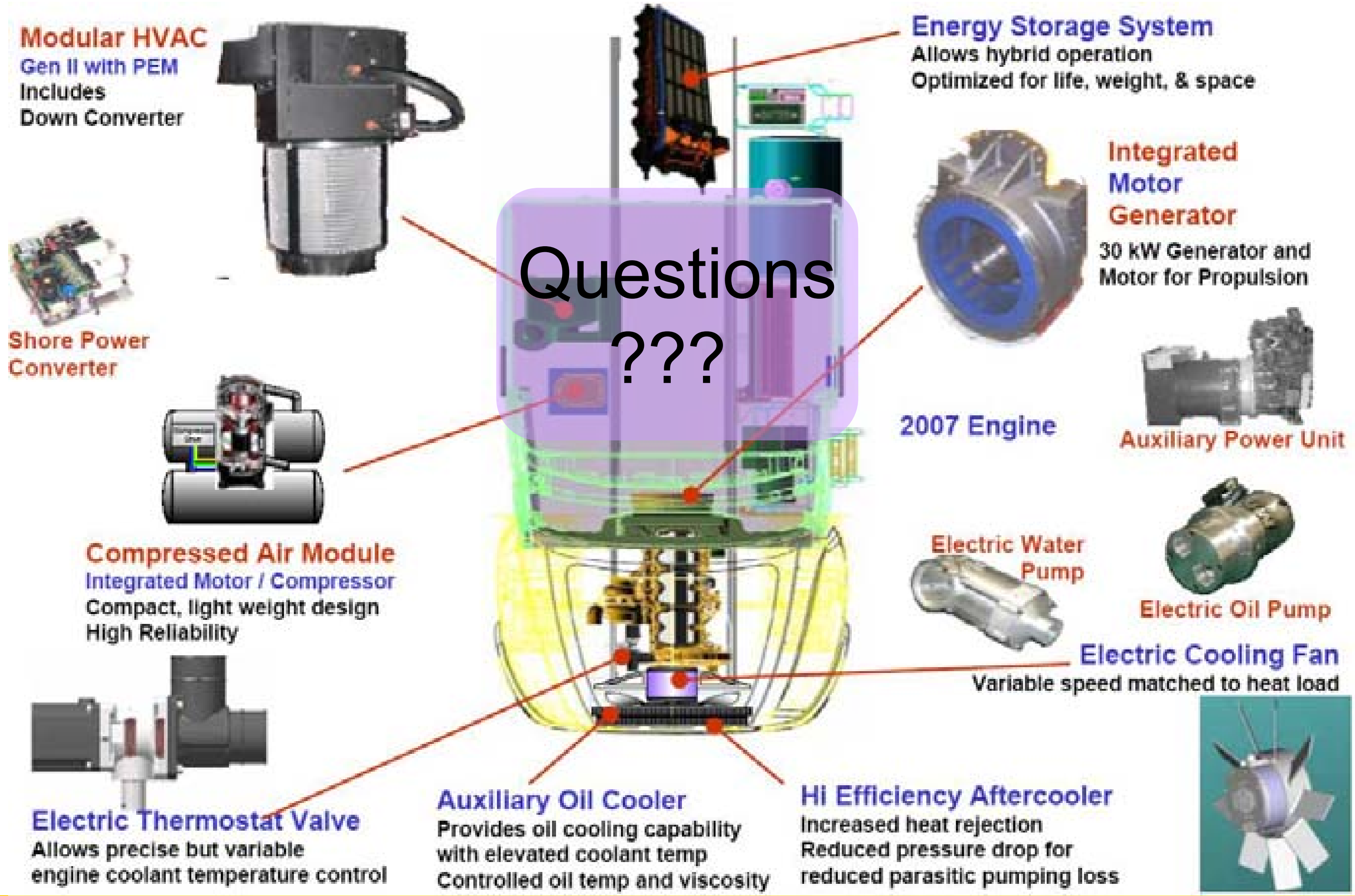
Questions ???



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